(12) AUSTRALIAN PATENT ABSTRACT

(19) AU (11) AU-A-15359/83

(54) ELECTROMECHANICAL TRANSDUCER

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(21) 15359/83 (22) 3.6.83 (24) 8.6.82

(31) 82 09951 (32) 8.6.82 (33) FR

(43) 15.12.83

(51)3 GOIL 1/16 GOIL 1/18

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(74) SF

(57) Claim

1. An electromechanical transducer comprising at least one active element in the form of a film of a first material having piezoelectric or piezoresistive properties and comprising means for amplifying a stress exerted on said film, conducting means being provided on the main faces of said film, wherein said amplifying means are formed by at least one layer of a second solid and deformable material incompressible in volume, said layer being securely attached to one of said main faces.

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

Form 10

COMPLETE SPECIFICATION

(ORIGINAL)

FOR OFFICE USE :

Class Int. Class

Application Number : 15359/83 .
Lodged :

Complete Specification Lodged :
Accepted :
Published :

Priority :

Related Art .

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Complete Specification for the invention entitled :

"ELECTROMECHANICAL TRANSDUCER AMPLIFYING STRESSES"

The following statement is a full description of this invention, including the best method of performing it known to me/us :

ABSTRACT OF THE DISCLOSURE

The invention relates to electromechanical transducers comprising a piezoelectric film.

The invention provides a transducer whose active element is formed by a film made from a piezoelectric or piezoresistive material inserted between two layers of a solid and deformable material incompressible in volume, said film adhering to layers which transmit thereto secondary stresses which may induce a substantially greater piezoelectric effect than the effect resulting from the initial stress applied to the film alone.

BACKGROUND OF THE INVENTION

The present invention relates to pressure sensors and transducers whose active element is formed by a film of piezoelectric or piezoresistive material. With the proposed structure, by using appropriate elements, piezoelectric or piezoresistive effects may be obtained substantially higher than those obtained for conventional structures.

Piezoelectric materials have the characteristic property of presenting a potential difference between two opposite faces in response to a mechanical stress. As for piezoresistive materials, their electric resistance is modified by the mechanical stresses which are applied thereto. As a first approximation, these electric properties are linear functions of the stress applied to the material considered. Piezoelectric materials are particularly interesting as transducers of mechanical energy into electric energy without requiring an external energy source. In some cases, it is particularly advantageous to have an electric effect produced by the piezoelectric or piezoresistive material which is the highest possible for questions of sensitivity or for avoiding application of the electric effect by subsidiary electronic devices.

It is known to increase the value of the electric effect in this kind of material by systems amplifying the mechanical effect, for example by a lever-arm. In such systems there are then two distinct parts : the piezoelectric or piezoresistive material and the amplification system. Another means of obtaining a high electric response with respect to the force applied is to generate the stress by bending. The active element is then in the form of a beam embedded at one end and undergoing a bending force at the other. The tension stresses which are thus generated inside the material are then very high, as well as the electric effect generated.

In many applications, for example in the case of hydrostatic pressure sensors, it is not convenient or it is even impossible to mechanically amplify the stresses to be measured or to use devices in the form of embedded beams.

So as to palliate these disadvantages, the invention provides a stacked structure in which a piezoactive film is inserted between two solid, deformable and incompressible bodies. When the structure is acted on by a force and is deformed, stresses are produced by said bodies on the faces of the film, which are converted by piezoelectric or piezoresistive effect into a higher electric magnitude variation than the same force would have produced if the bodies were indeformable or could slide over the faces of the film. Experience shows that the secondary stresses may induce piezoelectric or piezoresistive effects substantially greater than those which may be expected with the structures of the prior art.

SUMMARY OF THE INVENTION

The invention provides then an electromechanical transducer comprising at least one active element in the form of a film of a first material having piezoelectric or piezoresistive properties and comprising means for amplifying a stress exerted on said film, conducting means being provided on the main faces of said film, characterized in that said amplifier means are formed by at least one layer of a second solid and deformable material which is incompressible in volume, said layer being integral with one of said main faces.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood from the following description and accompanying figures in which :

Figure 1 is an isometric view of a piezoelectric transducer explaining the principle of the invention,

Figure 2 is an isometric view of a piezoelectric transducer where the mechanical effect is exerted perpendicularly to the piezoelectric film,

Figure 3 is a front view of a transducer showing deformation thereof following a mechanical stress,

Figure 4 is a silentbloc type device with integrated stress sensor,

Figures 5 and 6 are isometric views of a transducer in which the mechanical effect is exerted parallel to the piezo-

electric film, and

Figure 7 shows a variation of a transducer in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 will relate to the physical explanation of the invention. It shows an isometric view of a flat piezoelectric transducer comprising three elements forming a stack. A piezoelectric film 4 can be seen inserted between two elements 5 and 6 adhering to these elements. Elements 5 and 6 are made from a deformable and incompressible material. The transducer studied has, as shown in figure 1, the form of a right-angled parallelepiped whose sides are parallel to the system of orthonormed coordinates of direction 1, 2 and 3. L designates the length of the parallelepiped, l its width and its thickness is the sum Xp + Xe, with :

- Xe : total thickness of elements 5 and 6,
- Xp : thickness of the piezoelectric film.

It will be assumed that elements 5 and 6 have the same thickness $\frac{Xe}{2}$. The transducer is placed on a flat base 7 whose upper face 8 is situated in a plane parallel to the plane defined by axes 1 and 2. It is subjected to a force F_3 directed parallel to axis 3. The calculations which follow will be made on the following assumptions : force F_3 is applied over the whole of the upper surface S of element 6 itself when this latter is deformed ; base 7 is not deformed and does not retain element 5 during deformation thereof resulting from application of the force F_3. It will also be assumed that elements 4, 5 and 6 are mechanically homogeneous and isotropic.

Thus, variation $\mathcal{E}$, in directions 1, 2 and 3, of the dimensions of the transducer is given by HOOKE's law. This law should be applied to the piezoelectric material and to the deformable and incompressible material. Which gives :

deformable and incompressible material

$$\begin{cases} \sigma_1^e = \frac{1}{Ye}\left[\sigma_1^e - V_e(\sigma_2^e + \sigma_3^e)\right] \\ \sigma_2^e = \frac{1}{Ye}\left[\sigma_2^e - V_e(\sigma_1^e + \sigma_3^e)\right] \\ \sigma_3^e = \frac{1}{Ye}\left[\sigma_3^e - V_e(\sigma_1^e + \sigma_2^e)\right] \end{cases}$$

piezoelectric material

$$\begin{cases} \mathcal{E}_1^p = \frac{1}{Yp}\left[\sigma_1^p - V_p(\sigma_2^p + \sigma_3^p)\right] \\ \mathcal{E}_2^p = \frac{1}{Yp}\left[\sigma_2^p - V_p(\sigma_1 p + \sigma_3^p)\right] \\ \mathcal{E}_3^p = \frac{1}{Yp}\left[\sigma_3^p - V_p(\sigma_1^p + \sigma_2^p)\right] \end{cases}$$

In these equations, Y is YOUNG's modulus, V the coefficient of POISSON, σ_i the stress in a direction i. The characteristics relating to the piezoelectric film bear the index e and those relating to the material of elements 5 and 6 the index p.

The dimensional variations of elements 5 and 6 are calculated as if these elements formed but a single block. Since film 4 adheres to elements 5 and 6, there is no sliding between the surfaces of these elements. The conditions at the limits permit the statement that $\mathcal{E}_1^e = \mathcal{E}_1^p$ and $\mathcal{E}_2^e = \mathcal{E}_2^p$. There is no force applied in directions 1 and 2 and the initial thickness of the different elements being respectively the same along axes 1 and 2 :

$$\begin{cases} \sigma_1^e Xe + \sigma_1^p Xp = 0 \\ \sigma_2^e Xe + \sigma_2^p Xp = 0 \end{cases}$$

The force applied to the upper face of area S is such that :

$$\sigma_3^e = \sigma_3^p = \frac{F_3}{S} = \sigma_3$$

From this set of equations we have :

$$\sigma_1^p = -\sigma_3 \cdot \frac{Xe}{Xp}\left(\frac{\nu_e}{Ye} - \frac{\nu_p}{Yp}\right)\left[\frac{1-\nu_e}{Ye} + \frac{Xe}{Xp}\left(\frac{1-\nu_p}{Yp}\right)\right]^{-1} \qquad (1)$$

which is the stress exerted on the piezoelectric film in direction 1. Since this structure is symmetrical in directions 1 and 2, we have $\sigma_1^p = \sigma_2^p$.

We can get an idea of the gain of the piezoelectric effect obtained with this transducer by taking the case of a structure formed from a film of piezoelectric polymer such as vinylidene polyfluoride (PVF_2) and whose elements 5 and 6 are formed by an elastomer such as synthetic polyisoprene. The geometrical and mechanical characteristics of the elements forming such a transducer being the following.

	Elastomer (e)	Piezofilm (p)
Thickness	X_e = 6mm	X_p = 30μm
Surface	S = 1 cm^2	S = 1 cm^2
Young's modulus	$Y_e = 3.10^7 N/m^2$	$Y_p = 3.9\ 10^9 N/m^2$
Coeff. of Poisson	ν_e = 0.5	ν_p = 0.3
Elongation in directions 1, 2, 3	$\varepsilon_1^e, \varepsilon_2^e, \varepsilon_3^e$	$\varepsilon_1^p, \varepsilon_2^p, \varepsilon_3^p$
Stresses in directions 1, 2, 3	$\sigma_1^e, \sigma_2^e, \sigma_3^e$	$\sigma_1^p, \sigma_2^p, \sigma_3^p$
Pieozelectric coefficients	0, 0, 0	D_{31}, d_{32}, d_{33} = (-13,-2,17) pC/N

we obtain $\sigma_1^p = -63\,\sigma_3$

Since the structure is symmetrical in directions 1 and 2, we have : $\sigma_1^p = \sigma_2^p$. For a force 1N applied in direction 3, the charges generated on the main faces of the piezoelectric film are :

$$\Delta Q = \sigma_1^p d_{31} + \sigma_2^p d_{32} + \sigma_3^p d_{33}.$$

The numerical application gives :

$$\Delta Q = -63 d_{31} - 63 d_{32} + d_{33} = 962\ pC.$$

If electrodes are provided at the interfaces of film 4 and elements 5 and 6, the potential difference ΔV which may be collected at the terminals of these electrodes is given by the relationship : $\Delta V = \frac{\Delta Q}{C}$, C being the capacity present between the electrodes, i.e. $C = \varepsilon_o . \varepsilon_{pVF_2} . \frac{S}{Xp}$. In this latter expression, ε_c represents the permittivity of the vacuum and ε_{pVF_2} the relative permittivity of the material used for forming the film in the example chosen, i.e. $\varepsilon_{pVF_2} = 12$. Then we have $\Delta V = 2.8V$. If the same force (1N) were applied to a simple PVF_2 film having the same characteristics, an amount of charges available on the main faces of the film ΔQ would be obtained solely proportional to d_{33}, i.e. a potent-ential difference $\Delta V = 5.10^{-2}V$.

The proposed structure allows then a conversion gain of mechanical energy into electrical energy to be obtained much higher with respect to a piezoelectric film alone. In the example proposed the conversion gain is $\frac{2.8}{5.10^{-2}} = 56$. Formula (1) may be expressed as a function of the ratio $\frac{Xp}{Xe}$ by a relationship of the form $\sigma_1^p = - \frac{\alpha \cdot \sigma_3}{\beta + \mu \frac{Xp}{Xe}}$

α, β and μ being then parameters characteristic of the materials used for constructing the transducer. It can be seen from this relationship that, to have high conversion gains, $Xp \ll Xe$. By keeping the same elastomer thickness the conversion gain may be increased by choosing PVF_2 films of a thickness of 12 microns or even 6 microns.

Conversely, if a potential difference is applied between the electrodes of the transducer, the resulting mechanical effect is also higher than in the case of a piezoelectric film used alone. The thickness variations of the transducer and of the film used alone are in a ratio equal to the previously calculated conversion gain.

The electrodes situated at the interfaces of the piezoelectric film 4 and plates 5 and 6 may be formed by deposit-

ing a conducting material such as aluminium on the film, elements 5 and 6 then being bonded to the conducting faces of the film. So as to avoid metalizing the main faces of the piezoelectric film, it is advantageous to make elements 5 and 6 conductive by incorporating therein conducting particles. In the case of the above-described transducer, the elastomer forming elements 5 and 6 may comprise carbon black which provides them with sufficient conduction to transmit the potential difference generated on the main faces of the piezoelectric film. The adhesion of the elastomer layers to the PVF_2 film must be sufficient so as to avoid sliding between the different elements forming the piezoelectric transducer. With synthetic poly-isopropene as elastomer, it is sufficient to thoroughly clean these elements with alcohol or trichlorethylene so as to obtain good adhesion. A transducer in accordance with the invention may be used for measuring a hydrostatic pressure. For this the transducer shown in figure 1 may be used. The calculation of the stresses is made from the above mentioned HOOKE equations by taking into account new conditions at the limits. As before, there is no sliding between the piezoelectric material film and the layers of the deformable and compressible material : $\varepsilon_1^e = \varepsilon_1^p$ and $\varepsilon_2^e = \varepsilon_2^p$. It is assumed that the liquid in which the transducer is plunged exerts a stress σ on the assembly of the structure and in directions 1, 2 and 3, namely :

$$\sigma_1^p . Xp + \sigma_1^e . Xe = \sigma (Xp + Xe)$$

$$\sigma_2^p . Xp + \sigma_2^e . Xe = \sigma (Xp + Xe)$$

$$\sigma_3^p = \sigma_3^e = \sigma$$

From this set of equations we have :

$$\sigma_1^p = \sigma \left[\left(\frac{\nu p}{Yp} - \frac{\nu e}{Ye} \right) + \frac{1-\nu_e}{Ye} \cdot \frac{Xp+Xe}{Xe} \right] \left[\frac{1-\nu_p}{Yp} + \frac{1-\nu_e}{Ye} \cdot \frac{Xp}{Xe} \right]^{-1}$$

which is the stress exerted on the piezoelectric film in direction 1. If the dimensions of the transducer in directions 1 and 2 are equal (l = L), we have $\sigma_1^p = \sigma_2^p$. With elastomer and piezoelectric materials whose electric and mechanical

characteristics have been mentioned above, we get $\sigma_1^p = \sigma_2^p = 0.85\sigma$. The amount of charges developed on the main faces of the piezoelectric film is then $0.58d_{31} + 0.58d_{32} + d_{33} = 8pC/N$. An identical PVF_2 film used alone would develop a hydrostatic piezoelectric coefficient $d_H = d_{31} + d_{32} + d_{33} = 2pC/N$. We have then, with a structure in accordance with the invention, a conversion gain of mechanical energy into elec - tric energy equal to 4.

The structure described in figure 1 also allows a potential difference to be collected on the main faces of the piezoelectric film corresponding to an amplification of a stress exerted along one of axes 1 or 2. If the transducer is stretched , for example along axis 1, the material of layers 5 and 6 contributes to greatly accentuating the contraction of film 4 in direction 2. There occurs, in this direction, a striction of the film which may be high towards the middle of the structure. Through an appropriate choice of the different characteristics of the materials used, it is possible to cause film 4 to undergo a stress σ_2 much higher than that exerted in direction 1. The new conditions at the limits which allow the HOOKE equations to be resolved are :

- no sliding between film 4 and layers 5 and 6 : $\varepsilon_1^p = \varepsilon_1^e$ and $\varepsilon_2^p = \varepsilon_2^e$;
- no stress in direction 3 : $\sigma_3^e = \sigma_3^p = 0$
- it is assumed that the stress σ is applied to the whole of the structure in direction 1 :

$$\sigma_1^e \; Xe + \sigma_1^p \; Xp = \sigma (Xe + Xp)$$

We get : $\sigma_2^p = -\sigma \frac{Xe + Xp}{Ye.Yp.Xp} (\nu_e - \nu_p) D^{-1}$

with $D = (1-\nu_p^2)\frac{Xe}{Xp.Yp^2} + \frac{2(1-\nu_e.\nu_p)}{Ye.Yp} + (1-\nu_e^2)\frac{[illegible]}{[illegible]}$

By choosing the following parameters :

$Xe = 2mm, \nu_e = 0.5, Ye = 10^{[illegible]} N/m^2$

$Xp = 10$ microns, $\nu_p = 0.3$, $Yp = 2.10^9 N/m^2$

we get $\sigma_2^p = -11\sigma$. In this case, the piezoelectric film is

subjected to a stress in direction 2 which is 11 times higher than the stress applied in direction 1.

In the above discussed cases, the stress exerted on the transducer should be evenly spread over the surfaces of application of the mechanical effect so as to avoid corner effects more especially.

Figure 2 is an isometric view of a piezoelectric transducer in accordance with the invention in a practical application thereof. The transducer can be seen formed from a film 9 of piezoelectric material, for example PVF_2, sandwiched between two layers 10 and 11 of deformable and incompressible material. Layers 10 and 11 may be formed from poly-isoprene made conductive by the presence of carbon black. Layers 10 and 11 are integrated with film 9 by simply cleaning with alcohol or trichlorethylene. The main faces of the transducer may have an area of $1cm^2$, the thicknesses of layers 10 and 11 are for example 3mm and that of the film may be about 30 microns. A brass stud 12 ensures the distribution of force F normal to the main faces of the transducer. It may adhere to layer 10, for example by means of a conducting adhesive. Layer 11 is also fixed to a rigid, flat and conducting support 13. Connections 14 and 15 allow the voltage V generated by the piezo electric effect to be picked up. When force F is applied, elements 9, 10 and 11 have their dimensions situated in the horizontal plane deformed. Since elements 12 and 13 are practically indeformable, they naturally tend not to cause an even deformation of the structure. This is what is shown in figure 3 which is a front view of the same transducer as before and which is subjected to a force F. The bulging will be noted of the sides of the transducer under the effect of force F and because of the adherence of layers 10 and 11 respectively to stud 12 and to support 13. In fact, the forces applicable to the transducer do not appreciably modify the horizontal dimensions of elements 9, 10 and 11 and the above developed theoretical considerations remain largely valid.

Figure 4 is one example of application of a transducer according to the invention to devices of the "silentbloc" type

with integrated stress sensor. The device has been chosen with a cylindrical shape. It is formed from a piezoelectric material film 30, for example PVF_2, inserted between two layers 31 and 32 of a deformable and incompressible material such as poly-isoprene. Elements 30, 31 and 32 may be fixed together by simply cleaning with alcohol or trichlor ethylene. The whole may be mounted on systems in which it is desired to absorb the noises or vibrations through fixing elements 33 and 36 which are formed from a washer 35 or 38 integral with a threaded rod 34 or 37. Insulating washers 39 and 40 are inserted between the fixing elements and layers 31 and 32. These insulating washers may be required when the fixing elements are made from metal and layers 31 and 32 are made conductive. Elements 33, 39, 36 and 40 may be firmly secured together and with layers 31 and 32 by bonding. If layers 31 and 32 are conductive, connections 41 and 42 may be fixed thereto so as to transmit the voltage generated by piezoelectric effect. Thus, a silentbloc is obtained with integrated stress sensors.

It is also within the scope of the invention to use these transducers as piezoelectric keyboards so as to obtain increased sensitivity with respect to conventional devices. The keys may be advantageously formed by composite structures where the stress is exerted perpendicularly to the piezoelectric film.

Figure 5 shows a transducer in accordance with the invention able to be subjected to a force exerted along one of its horizontal dimensions. The transducer is formed from a film 16 sandwiched between two layers 17 and 18 integral with film 16. These elements are for example formed from the same materials as before. Connections [illegible] and [illegible] connect respectively conducting layers 17 and 18 to the outside. Rigid and insulating elements 19 and 21 are fixed at the opposite ends of the composite structure formed by elements 16, 17 and 18. Element 21 is firmly secured to a fixed base 20. Element 19 is able to subject the transducer to an elongation force in direction 1.

Figure 6 shows the same device as that described with reference to figure 5. An elongation force F is applied to the transducer in direction 1. In this case, a voltage V appears at the terminals of connections 22 and 23. As calculations have demonstrated, the fact of disposing deformable and incompressible elements in intimate relationship with a piezoelectric film allows a higher voltage V to be developed than if the film were used alone. Elongation of the transducer in direction 1 causes modifications of its section in planes parallel to the plane defined by directions 1 and 2. At the transducer-element 19 and 21 interfaces, the section does not change since these elements are rigid but this has no appreciable consequence on the theoretical results.

Figures 5 and 6 illustrate a structure which allows amplification of a stress exerted in a direction parallel to the electrodes, or to the elements serving as electrodes, which are used for recovering the voltage created by piezoelectric effect. A flat stacked structure has been described but it falls within the scope of the invention to manufacture structures having another shape, for example cylindrical as shown in figure 7.

In this figure, it can be seen that the structure has a symmetry of revolution about axis zz'. A piezoelectric film 50 in the form of a tube is sandwiched between two elements 51 and 52 made from a deformable and incompressible material, element 51 being a cylinder which occupies the inside of tube 50 and element 52 surrounding tube 50. Examples of materials forming the different parts of the strucutre have already been revealed. In this type of transducer, the forces are exerted parallel to axis zz' and produce for the whole of the structure compression or elongation stresses.

We saw above that in the case where the force exerted on the transducer is due to hydrostatic pressure, the energy conversion gain is of the order of 4 with respect to the piezoelectric film used alone. In measuring hydrostatic pressure, the voltage generated by piezoelectric effect is all the greater the larger the surface of the piezoelectric film.

To increse the sensitivity of the sensor, its dimensions must then be increased. The structure proposed lends itself very well to the provision of large surfaces. It is possible, so as to reduce the space occupied to roll up the assembly. The use of large surfaces implies bending forces on the piezoelectric film. These do not intervene in the measurement because of the verysmall thickness of the film (of the order of 6 to 30 microns) and since, because of the symmetry of the structure, the film is on the neutral fiber of the transducer. Which means that only pressures are measured and not the effects due to water movements.

It also falls within the scope of the invention to construct transducers comprising several piezoelectric films, each being separated by a layer of deformable and incompressible material. Thus, different voltage sources may be provided coming from the piezoelectric effect.

It is possible, in the proposed structures, to replace the piezoelectric film by a piezoresistive film and to obtain in the same way as before an electromechanical conversion gain. In this case, an external electric source must be employed in order to use the piezoresistive effect.

Different configurations are possible for the transducer : a single layer of deformable and incompressible material may be used ; several piezoelectric films may be placed side by side ; stacked structures of several films may be formed, each being separated from the others by said layers ; finally, combinations of these different configurations may be used.

The structure of the invention allows as it were the stresses which are applied thereto to be appreciably amplified. By using materials having high piezoelectric constants, it is possible to obtain piezoelectric effects for the structure of the same order of size as the effects obtained from ceramics of type PZT (formed of lead, zirconium and titanium oxides). It should also be noted that the proposed structure which may be entirely polymeric (case of a polarized PVF_2 film inserted between two elastomer layers charged with carbon black) is insensitive

to the bending effects when the piezoelectric film is very thin (of the order of 10 microns) and when it is placed symmetrically in the structure.

The structure of the invention may advantageously replace conventional structures in all fields of use in which the piezoelectric effects are of a low frequency. This is the case, for example, for keyboards and piezoelectric scales, systems of the silentbloc type with integrated stress sensor, hydrostatic sensor

The claims defining the invention are as follows:
~~WHAT IS CLAIMED IS~~ :

1. An electromechanical transducer comprising at least one active element in the form of a film of a first material having piezoelectric or piezoresistive properties and comprising means for amplifying a stress exerted on said film, conducting means being provided on the main faces of said film, wherein said amplifying means are formed by at least one layer of a second solid and deformable material incompressible in volume, said layer being securely attached to one of said main faces.

2. The electromechanical transducer as claimed in claim 1, wherein said layer serves as a conducting means;

3. The electromechanical transducer as claimed in claim 2, wherein the material forming said layer is made conducting by incorporating conducting particles therein.

4. The electromechanical transducer as claimed in claim 3, wherein said conducting particles are carbon black.

5. The electromechanical transducer as claimed in claim 1, wherein said second material is an elastomer.

6. The electormechanical transducer as claimed in claim 5, wherein said elastomer is poly-isoprene.

7. The electromechanical transducer as claimed in claim 1, in a cylindrical form, said film having the form of a tube adhering to at least one layer cylindrical in shape.

8. The electromechanical transducer as claimed in claim 1, wherein the mechanical effect is exerted perpendicularly to the main faces of said film.

9. The electromechanical transducer as claimed in claim 1, wherein the mechanical effect is exerted parallel to the main faces of said film.

10. The electromechanical transducer as claimed in claim 1, wherein the mechanical effect is transmissible through rigid elements.

11. A keyboard comprising keys using the piezoelectric effect, wherein said keys are formed by electromechanical transducers such as claimed in claim 1.

DATED this TWENTY SEVENTH day of MAY, 1983

THOMSON-CSF

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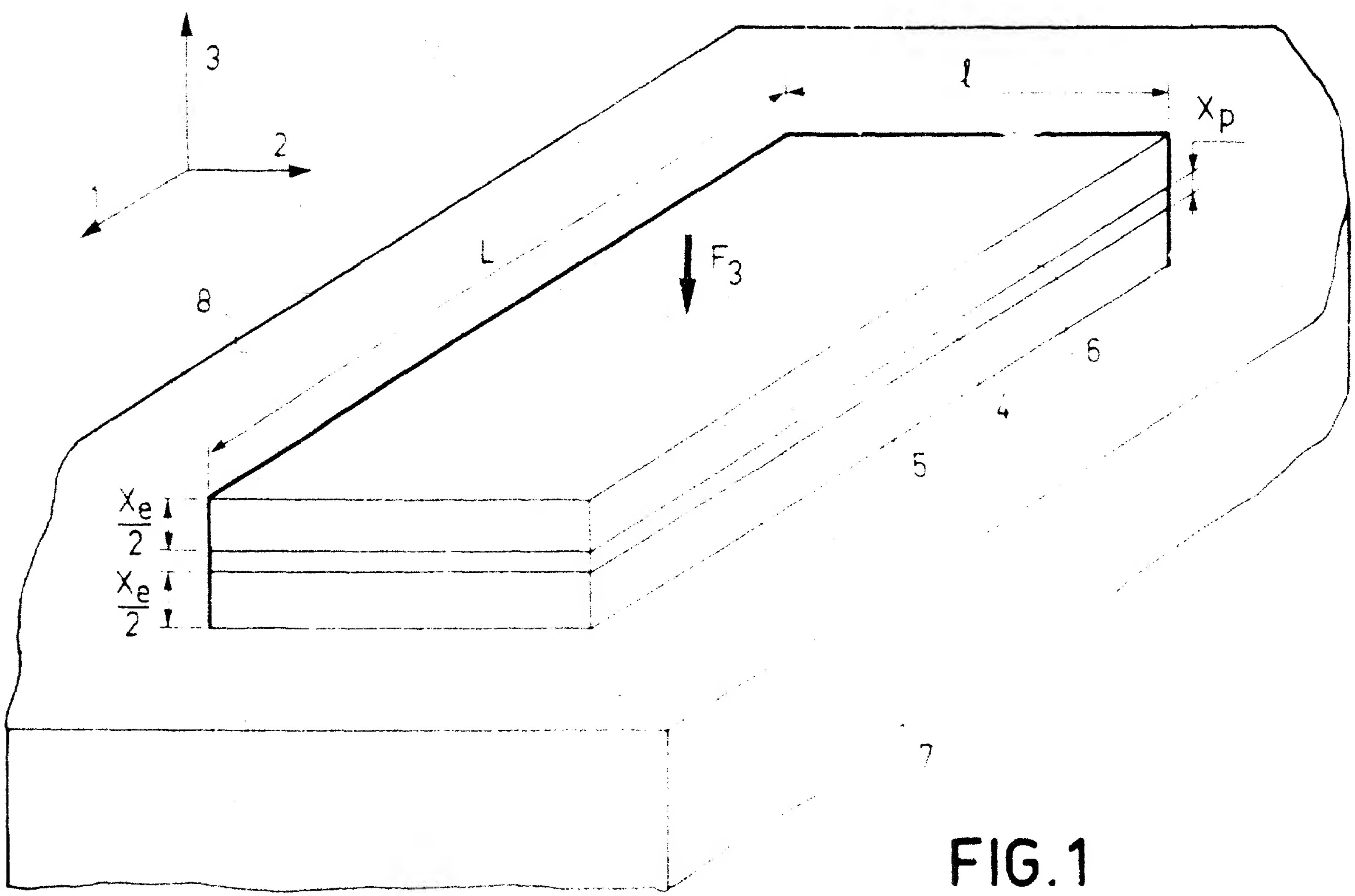


FIG.1

FIG. 2

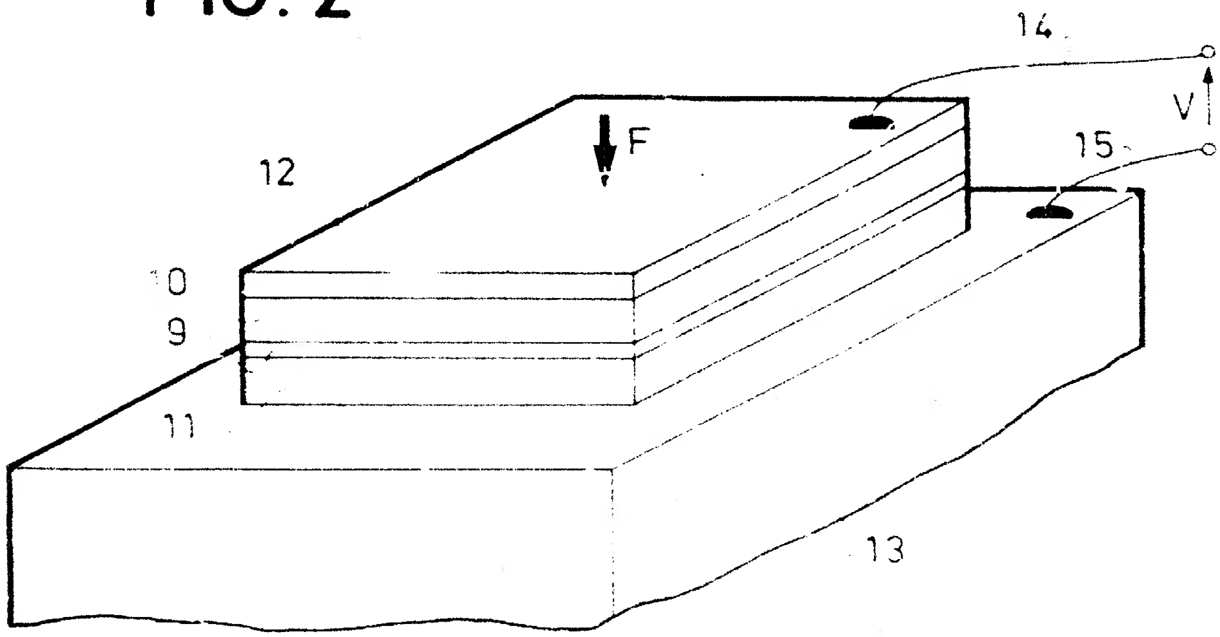


FIG. 3

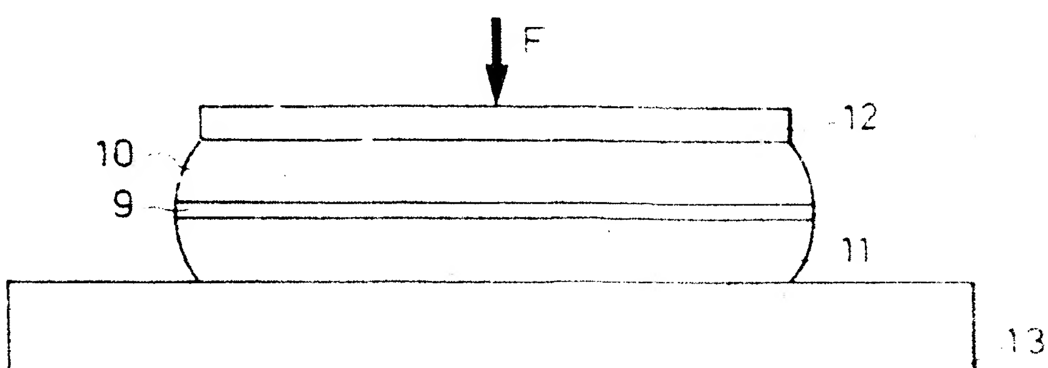


FIG. 4

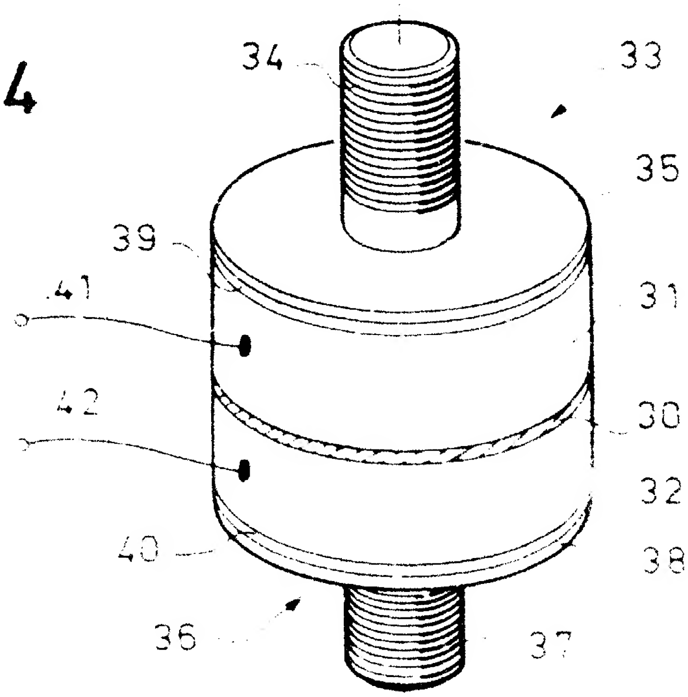
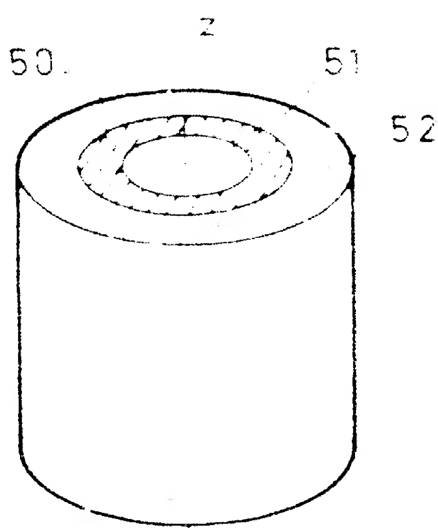


FIG. 7



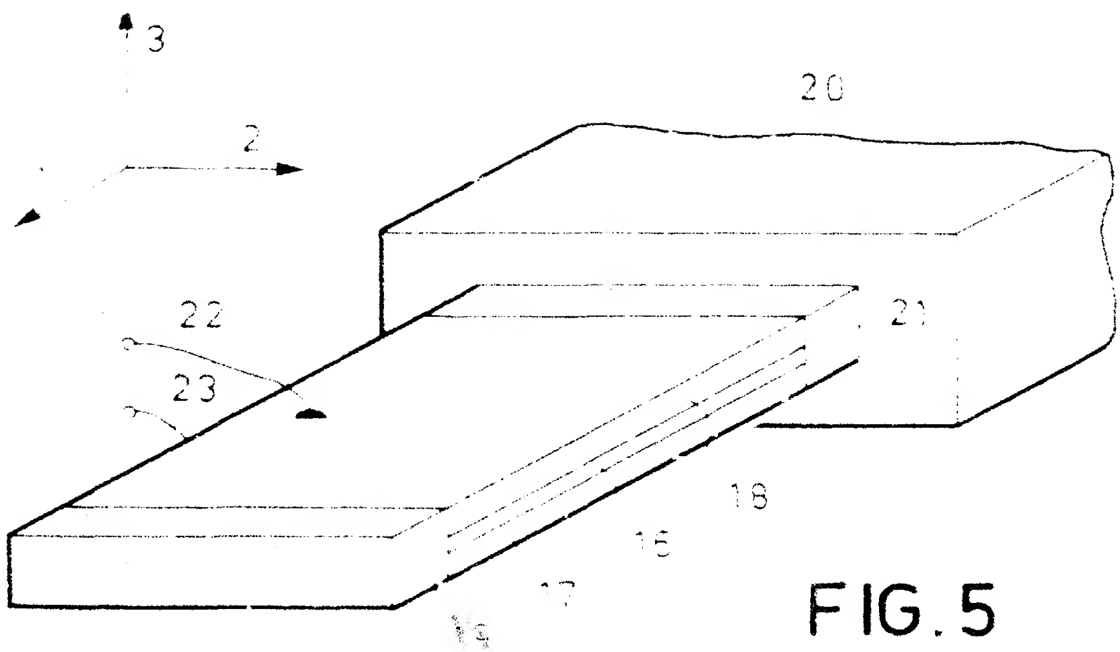


FIG. 5

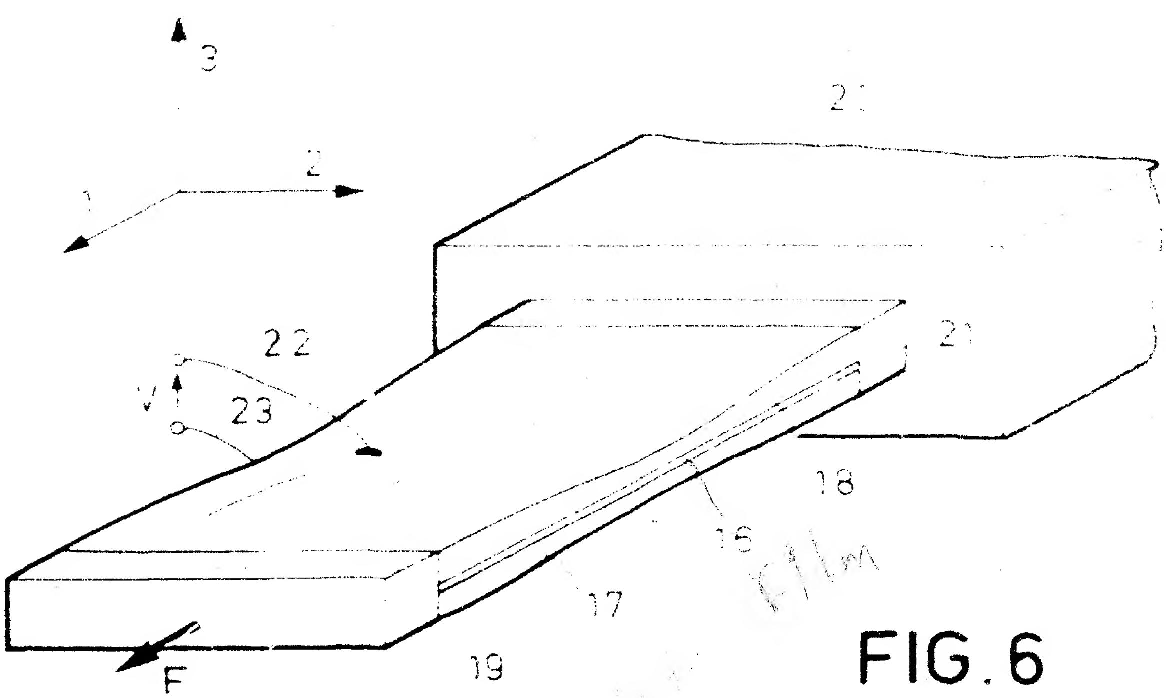


FIG. 6